ACID GAS RELIEF CHALLENGES IN THE NATURAL GAS TREATMENT INDUSTRY

Laurance Reid Gas Conditioning Conference
February 21-24, 2016 – Norman, Oklahoma USA

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ABSTRACT

Acid gas relief issues are important for any company that deals with a pressurized acid gas stream. Frequently these systems operate at high pressures and the fluids are in the supercritical or dense phase state. Natural gas facilities that have acid gas injection as a means of disposal, facilities that recover CO_2 for other uses, and facilities that have a high CO_2 and/or H_2S content in the inlet natural gas feed stream such as the La Barge, Riley Ridge, Lost Cabin, and Century plants all have high pressure acid gas streams. In high pressure acid gas relief situations the physical properties are difficult to estimate using standard physical property packages. The relief valve sizing methodology differs from liquid and gas relief when the fluid is supercritical or non-ideal. The state of the acid gas after it passes through the relief valve can pose header design challenges and there is a need to consider thermal relief valves in high pressure acid gas applications.

This paper presents the methodology for sizing relief valves for supercritical or dense phase acid gas fluids and how this differs from typical liquid and gas relief situations. The importance of accurate physical properties of the acid gas fluid will be presented and examples of sizing calculations using different fluid compositions will be shown as illustration. Relief gas disposal systems for acid gas systems will also be presented, with strategies provided for designing a safe relief system that minimizes the number of relief devices required.

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Introduction

Relief devices and relief disposal systems are the last line of defense that protects equipment and personnel from the high energy forces that exist in the daily operation of processing facilities. The proper sizing and selection of relief devices and the disposal system components such as piping, knockout drums, flare tips, etc. entails a large engineering effort that considers process operations well outside of the normal heat and material balance parameters. This extensive effort and the related equipment selected is all for a system that will hopefully rarely, if ever, be put into operation during the facility's lifetime. Therefore, minimizing the costs of the relief system is desired while still ensuring it will operate properly when, and if, it is necessary to protect the facility and the personnel operating it.

The sizing of acid gas (carbon dioxide and/or hydrogen sulfide) relief devices and disposal systems is further complicated by the way that these fluids behave when they are rapidly expanded through a relief device. It is common to have the acid gas fluid undergo partial condensation or deposition in addition to a substantial drop in temperature as it passes through the relief device. These possible phase changes and the non-ideality of the acid gas in general make the typical gas and liquid equations that assume ideal behavior normally used to size a relief valve unsuitable, and an alternate sizing method must be employed. It is important to design the relief disposal system in these situations to account for the presence of multiple phases, low temperatures, and the potential for interaction with other relief streams in the disposal system.

One of the most cost-effective methods for dealing with difficult relief systems is to avoid the need for some relief devices in the first place. Systematically considering relief scenarios early in the design of a new unit operation or a new facility can reduce the size and number of required relief devices, while still ensuring the safe operation of the unit. Minimizing the size and number of relief devices can significantly reduce the cost and complexity of the relief disposal system.

Methodology for Sizing Relief Valves in Supercritical or Dense Phase Service

API-520 Part I is the American Petroleum Institute's standard for sizing pressure relief valves to protect equipment that has a maximum allowable working pressure (MAWP) of 15 psig or greater. The equations for sizing relief devices in critical vapor flow, subcritical vapor flow, steam flow, and liquid flow are presented in the main text of API-520 Part I and are explained in some detail. For a gas or vapor stream, the flow across the relief valve is first checked to see if the flow is choked based upon the limiting velocity of the gas through the nozzle, which is the sonic velocity of the fluid at those conditions. Assuming that the flow is determined to be choked, also known as critical vapor flow, the relief valve is sized according to Equation 1. In this paper, sizing devices using this equation may be referred to as the "ideal method."

$$A = \frac{W}{CK_d P_1 K_b K_c}\sqrt{\frac{TZ}{M}} \qquad \text{Eq. 1}$$

Where:

A = Area (in.^{2})
W = Mass Flow (lb/hr)
C = Coefficient for C_p/C_v
K_d = Effective Coefficient of Discharge
K_b = Capacity Correction Factor for Backpressure
K_c = Combination Correction Factor when Rupture Disk Also Installed
P_1 = Relieving Pressure (psia)
T = Temperature (°R)
Z = Compressibility
M = Molecular Weight (lb/lbmol)

Equation 1 has a wide applicability and is used routinely to size relief valves in critical flow service. There are limitations to the applicability of Equation 1 though as it assumes that the pressure-specific volume relationship along an isentropic path is constant and assumes the fluid is an ideal gas. In some cases this assumption is not appropriate, as API-520 indicates in Section 5.6.1:

> However, the validity of this assumption may diminish at very high pressures or as the vapor or gas approaches the thermodynamic critical locus [critical point]. One indication that the vapor or gas may be in one of these regions is a compressibility factor, Z, less than approximately 0.8 or greater than approximately 1.1.

For some natural gas streams with large fractions of acid gases present or in acid gas streams compressed to relatively high pressures, the gas (or fluid if it is supercritical) compressibility factor can deviate appreciably from a value of unity. Figure 1 shows the compressibility factor for a pure carbon dioxide stream as a function of pressure at various temperatures. In this paper, all data involving pure CO_2 is generated from the Span-Wagner equation while data for mixtures of CO_2 and H_2S is generated from the Advanced Peng Robinson equation of state in the VMGSim modeling software.

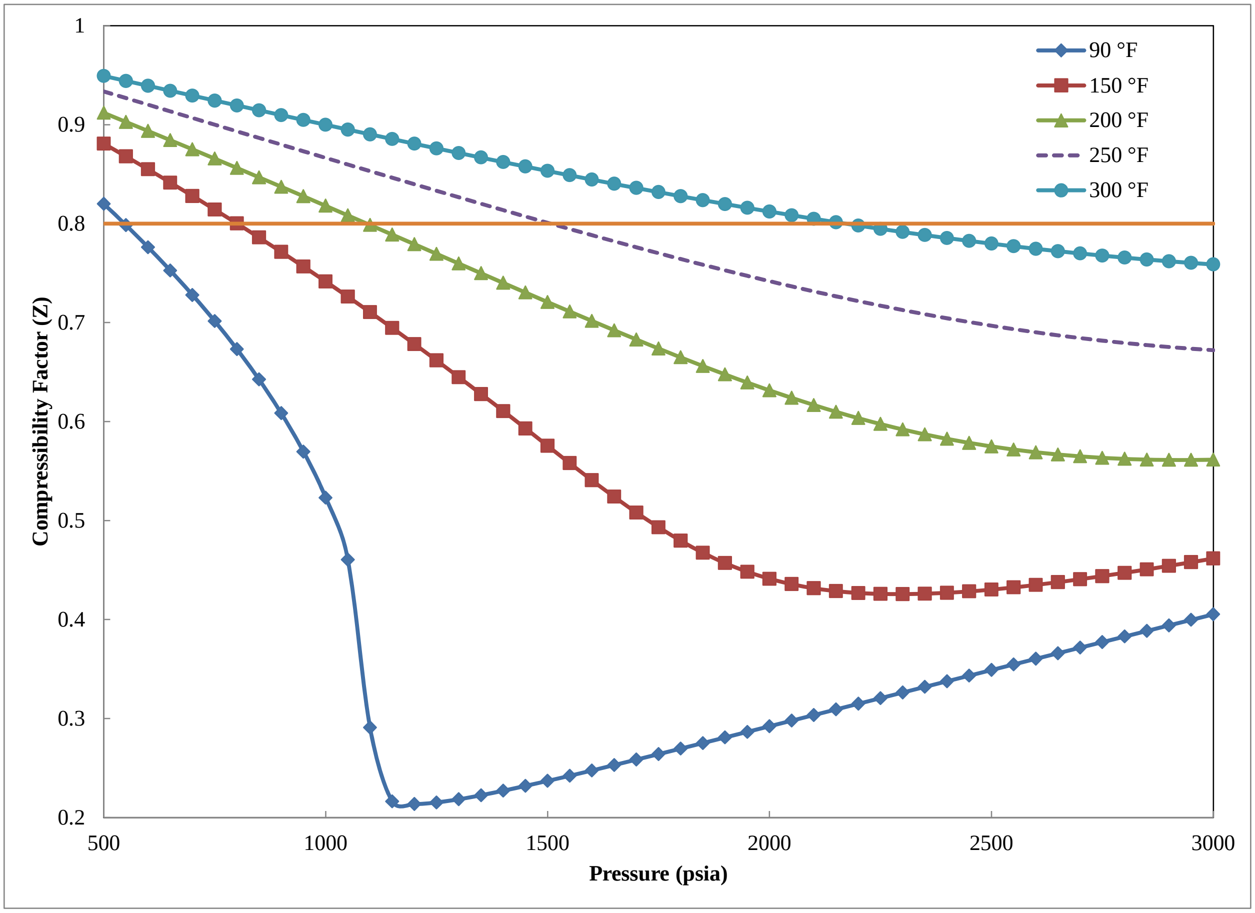

Figure 1. Compressibility Factor of Pure CO_2 at Various Pressures and Temperatures.

Figure 1 illustrates that there are many cases where Equation 1 is not applicable for sizing a relief valve in pure carbon dioxide (CO_2) service. As the fluid conditions approach the critical point of 1,071.6 psia and 87.8 °F, the compressibility factor deviates considerably from the prescribed limits. At all temperatures in Figure 1 there are pressures at which Equation 1 is not suitable for sizing the relief valve. In these cases, API 520 advises the user to “see Annex B for guidance on sizing when this section is not applicable.”

Acid gas streams that contain significant fractions of hydrogen sulfide (H_2S) also have a substantial pressure and temperature range where the ideal method is not suitable for calculating the required size of relief devices. Figure 2 below shows the same range of temperature and pressure conditions as Figure 1 for a stream with a composition of 50% CO_2 and 50% H_2S (molar).

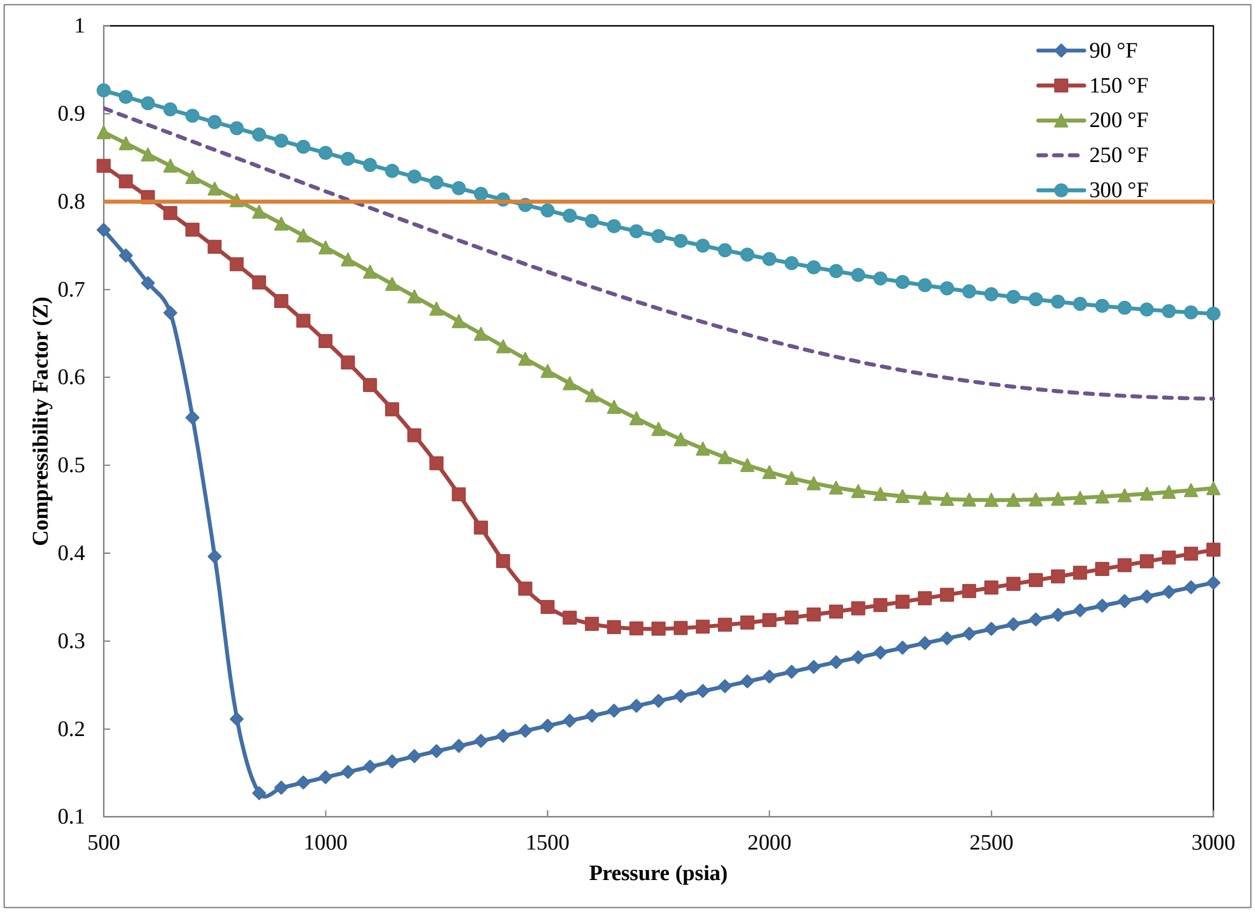

Figure 2. Compressibility Factor of 50% CO_2 / 50% H_2S (molar) Stream at Various Pressures and Temperatures.

Annex B in API-520 Part I provides the sizing techniques that should be used in situations where the assumptions made to develop Equation 1 are not appropriate. The technique presented in Annex B is an iterative approach and begins with a formula to calculate the mass flux through a nozzle as shown in Equation 2 (USC units).

$$G^2 = \left[\frac{-2 * \int_{P1}^{P} 32.174 * 144 * v * dP}{v_t^2} \right]_{MAX} \qquad \text{Eq. 2}$$

Where:

G = Mass Flux (lb/ft^2s)
v = Specific Volume (ft^3/lb)
P = Pressure (psia)

Equation 2 is independent of the compressibility of the fluid and can be used for any homogenous fluid. What is critical for successful implementation of Equation 2 is accurate knowledge of the fluid's specific volume as a function of pressure at constant entropy since the methodology assumes the fluid expands across the relief device isentropically. Equation 2 can be further simplified by evaluating the integral numerically using the Trapezoidal rule and solving the equation at specific pressure intervals until a maximum mass flux is found or until the total backpressure of the system is reached. The accuracy of the calculation will depend in part on the step size used for the numerical solution of the integral; the smaller a pressure step used to solve the equation the more accurately the mass flux through the nozzle will be determined.

The maximum mass flux is then used to size the relief valve with the appropriate capacity correction factors as shown in Equation 3. In this paper, sizing a relief device using Equations 2 and 3 will be referred to as the mass flux method.

$$A = \frac{0.04 * W}{G * \Pi(K)} \qquad \text{Eq. 3}$$

Where:

A = Orifice Area Required (in.^{2})
W = Mass Flow Rate (lb/hr)
G = Mass Flux (lb/ft^{2}s)
Π(K) = Product of Applicable Correction Factors

Table 1 below shows a snapshot of the iterative process of the mass flux method for Example 1. In Example 1, the relief valve is required to relieve 200 MMSCFD of pure carbon dioxide at 1,841 psia at 191 °F. As the throat pressure decreases from 1,841 psia at constant entropy, the specific volume of the fluid increases. The mass flux through the nozzle increases until it reaches a maximum and from that point on continues to decay. The compressibility of the fluid in this example is 0.633 and thus the ideal method is not appropriate for this situation. To further complicate the situation, the fluid may partially condense into a liquid as it passes through the valve which requires the calculation of the specific volume of a two phase mixture. The procedure for calculating the density of the two phase mixture is provided in Annex C of API-520. However, for this example the maximum mass flux is reached prior to the fluid entering the two phase region.

Table 1. Results of Mass Flux Method – Example 1.

Entropy	**Pressure at the Throat**	**Temp.**	**Fluid State**	**Specific Volume**	**Mass Flux**
Btu/lb-^{0}F	**psia**	**^{0}F**		**ft^3/lb**	**lb/s-ft^2**
-0.230339	1,233.3	133.3	Supercritical	0.0716	8,245
-0.230339	1,214.9	131.2	Supercritical	0.0724	8,299
-0.230339	1,196.5	129.0	Supercritical	0.0732	8,348
-0.230339	1,178.0	126.8	Supercritical	0.0740	8,393
-0.230339	1,159.6	124.6	Supercritical	0.0749	8,433
-0.230339	1,141.2	122.4	Supercritical	0.0758	8,468
-0.230339	1,122.8	120.1	Supercritical	0.0767	8,500

Entropy	Pressure at the Throat	Temp.	Fluid State	Specific Volume	Mass Flux
Btu/lb-^{0}F	psia	^{0}F		ft^3/lb	lb/s-ft^2
-0.230339	1,104.4	117.8	Supercritical	0.0776	8,526
-0.230339	1,086.0	115.5	Supercritical	0.0786	8,549
-0.230339	1,067.6	113.1	Superheated	0.0796	8,567
-0.230339	1,049.2	110.7	Superheated	0.0806	8,581
-0.230339	1,030.8	108.3	Superheated	0.0817	8,591
-0.230339	1,012.4	105.8	Superheated	0.0828	8,596
-0.230339	**994.0**	**103.3**	**Superheated**	**0.0839**	**8,597**
-0.230339	975.6	100.7	Superheated	0.0851	8,594
-0.230339	957.2	98.1	Superheated	0.0863	8,587
-0.230339	938.8	95.5	Superheated	0.0876	8,576
-0.230339	920.3	92.8	Superheated	0.0889	8,560
-0.230339	901.9	90.1	Superheated	0.0903	8,540
-0.230339	883.5	87.3	Superheated	0.0917	8,516

The maximum mass flux is highlighted in Table 1 and occurs at a throat pressure of 994 psia. This mass flux will be used to calculate the required relief area in Equation 3. The other unknown in Equation 3 is the product of the correction factors ($\pi(K)$) that are used for the relief valve sizing. In order to select the appropriate correction factors, it is important to know what is occurring in the relief valve as the fluid expands through the valve, since the appropriate factors to use will depend on the state of the fluid as it enters and exits the relief valve. If the fluid behaves as a compressible fluid or reaches choked flow within the relief valve (as in the example above), then the correction factors for vapor and/or two-phase service may be appropriate. These factors can have a large impact on the area required for the relief valve and care should be taken when determining which factors are appropriate and the values to use for those factors.

The discharge coefficient K_d can be difficult to estimate appropriately when sizing a relief valve. This coefficient is used to estimate how much the mass flow rate will differ in an actual nozzle compared to the ideal nozzle assumed in the flow rate calculation. The API-520 standard suggests choosing a preliminary value based upon the state of the relieving fluid upstream of the relief orifice. The coefficient value can range from 0.975 for a vapor, 0.85 for a two phase fluid, and 0.62 for a liquid. Other literature sources and vendor guidance for two-phase fluid relief suggest using formulas to calculate K_d or prorating the coefficient based upon the fraction of liquid and gas in the relieving stream. When the actual relief valve is selected, the manufacturer should provide an actual coefficient value based upon testing of the valve. In high pressure acid gas relief situations, the fluid may not be a liquid or a vapor and there is some probability that the relief valve vendor will not have an actual coefficient value since the fluid is at an unusual condition and may ask the sizing engineer for guidance on the coefficient selection. In this example, a discharge coefficient (K_d) of 0.975 will be assumed since the fluid is superheated vapor below the critical pressure at the relief orifice during maximum mass flux. Table 2 shows suggested K_d factors to use when sizing relief valves depending on the fluid state. Trimeric developed this table based on review of the API methods and in consultation with pressure relief valve suppliers.

Table 2. Relief Valve Discharge Coefficients for Differing Fluid States at Relief Orifice.

Fluid State	Discharge Coefficient (K_d)
Liquid, Subcooled	0.62
Two-Phase Fluid, Quality < 0.5	0.65
Two-Phase Fluid, Quality > 0.5	0.85
Vapor, Pressure Above $P_{critical}$ and Variable Density	0.85
Vapor, Pressure Above $P_{critical}$ and Relatively Constant Density	0.65
Vapor, No Condensation, Close to Ideal Gas Behavior	0.975

The backpressure coefficient K_b will be assumed to be unity for this example, and this is a reasonable assumption if the backpressure in the acid gas disposal header is less than 30% of the set pressure of the valve and the valve is a balanced bellows design. The combination correction factor K_c will also be assumed to be unity for this example and will be unity unless a rupture disk is installed upstream of the relief valve.

Table 3 shows the sizing results using the mass flux and the ideal methods for Example 1 and shows the percent difference of the ideal method relative to the mass flux method. Each method uses the same correction factors (0.975) and relieving conditions, but the ideal method utilizes the compressibility factor and ideal gas specific heat capacity ratio while the mass flux method relies on property data at actual conditions.

Table 3. Sizing Results Using the Mass Flux Method and the Ideal Method – Example 1.

	Mass Flux Method	Ideal Method	Percent Difference
Area Required (in.^{2})	4.61	4.75	3%

For Example 1, the difference between the mass flux method and the ideal method is fairly small. This is not true across all potential relieving conditions however. Consider a second example where 200 MMSCFD of pure CO_2 is relieved at 1,599 psia and 110 °F. In Example 2 the same procedure is followed for the mass flux and ideal methods, with the iterative process results of the mass flux method shown in Table 4.

Table 4. Results of the Mass Flux Method – Example 2.

Entropy	Pressure at the Throat	Temp.	Fluid State	Specific Volume	Mass Flux
Btu/lb-^{0}F	psia	^{0}F		ft^3/lb	lb/s-ft^2
-0.32861	1,330.1	99.9	Supercritical	0.0264	9,610
-0.32861	1,310.9	99.1	Supercritical	0.0265	9,919
-0.32861	1,291.7	98.3	Supercritical	0.0266	10,214
-0.32861	1,272.6	97.5	Supercritical	0.0267	10,496
-0.32861	1,253.4	96.7	Supercritical	0.0268	10,765
-0.32861	1,234.2	95.8	Supercritical	0.0269	11,023
-0.32861	1,215.0	94.9	Supercritical	0.0270	11,270
-0.32861	1,195.8	94.0	Supercritical	0.0271	11,507
-0.32861	1,176.6	93.1	Supercritical	0.0273	11,733
-0.32861	1,157.5	92.2	Supercritical	0.0274	11,949
-0.32861	1,138.3	91.2	Supercritical	0.0275	12,154
-0.32861	1,119.1	90.2	Supercritical	0.0277	12,349
-0.32861	1,099.9	89.2	Supercritical	0.0279	12,531
-0.32861	1,080.7	88.2	Supercritical	0.0280	12,699
-0.32861	**1,061.5**	**87.1**	**Liquid**	**0.0283**	**12,845**
-0.32861	1,042.3	85.7	Two-Phase (Quality = 0.1180)	0.0291	12,707
-0.32861	1,023.2	84.2	Two-Phase (Quality = 0.1791)	0.0301	12,529
-0.32861	1,004.0	82.7	Two-Phase (Quality = 0.2152)	0.0311	12,360
-0.32861	984.8	81.2	Two-Phase (Quality = 0.2407)	0.0321	12,197
-0.32861	965.6	79.7	Two-Phase (Quality = 0.2603)	0.0331	12,035
-0.32861	946.4	78.1	Two-Phase (Quality = 0.2763)	0.0342	11,875
-0.32861	927.2	76.5	Two-Phase (Quality = 0.2898)	0.0353	11,715
-0.32861	908.1	74.9	Two-Phase (Quality = 0.3016)	0.0365	11,554
-0.32861	888.9	73.2	Two-Phase (Quality = 0.3121)	0.0377	11,392

As shown in Table 4, as the fluid expands isentropically it will pass through the relief orifice as a liquid and a two phase mixture is present in the next iteration that follows the peak mass flux value. As a result, the discharge coefficient K_d that is selected for the calculation may need to be a value of 0.62 for the liquid or a value of 0.65 for two-phase flow where the majority of the fluid is a liquid, per Table 2. The ideal sizing method would not reveal that this phase change within the relief valve is potentially occurring since it neglects the actual properties of the fluid in the relief orifice and will use the vapor K_d of 0.975 for the sizing calculation. Table 5 shows the sizing results using a discharge coefficient of 0.62 for the mass flux method and a discharge coefficient of 0.975 for the ideal method.

Table 5. Sizing Results Using the Mass Flux Method and the Ideal Method with Revised Discharge Coefficient – Example 2.

	Mass Flux Method	Ideal Method	Percent Difference
Area Required (in.^{2})	4.85	3.47	-28.6%

The ideal method estimates a smaller required area than the mass flux method. The difference in the calculations is large enough that the ideal method estimates that an API "M" orifice is required while the mass flux method estimates that an API "P" orifice is required. By using the ideal method calculation in this instance, the relief valve would be significantly under-sized and may not provide sufficient relief area for the actual relief scenario based on actual fluid properties and using the mass flux method.

Accurate Fluid Physical Properties at Relieving Conditions and the Effect of H_2S on Acid Gas Relief Calculations

As with any relieving system, using accurate fluid physical properties for acid gas is critical for accurately sizing the pressure relief valve and associated equipment. This becomes even more important when the mass flux method is employed to size the relief device since it depends on the actual physical properties of the fluid rather than the ideal gas heat capacity ratio and the compressibility of the fluid.

In acid gas systems, the presence of other species in the acid gas stream and the ratio of CO_2 to H_2S in the stream can elevate or depress the critical point of the mixture which will affect the physical properties of the fluid and potentially the method used to size the relief valve as indicated in Figure 2. In recent years process simulators have been able to more closely replicate the physical properties of acid gases at or above the critical point. However, it is prudent to utilize several different data sources for physical properties of a fluid prior to final sizing of a relief device to be confident that the physical properties are accurate.

Figure 3 compares the specific volume of pure CO_2 versus a CO_2 stream with 50% H_2S (molar) at 90 °F. The data indicate that the stream with H_2S approaches the critical point at a lower pressure than pure CO_2. The specific volume of the H_2S stream is much lower than the pure CO_2 stream for pressures ranging from about 800 to 1,000 psia, which is the region around the critical point for the 50% H_2S and 50% CO_2 (molar) stream.

Figure 4 illustrates that the difference in specific volume at 300 °F is less pronounced; at the higher temperature the stream with H_2S has a specific volume that ranges from about 1% to 10% higher than a pure CO_2 stream, for the conditions examined.

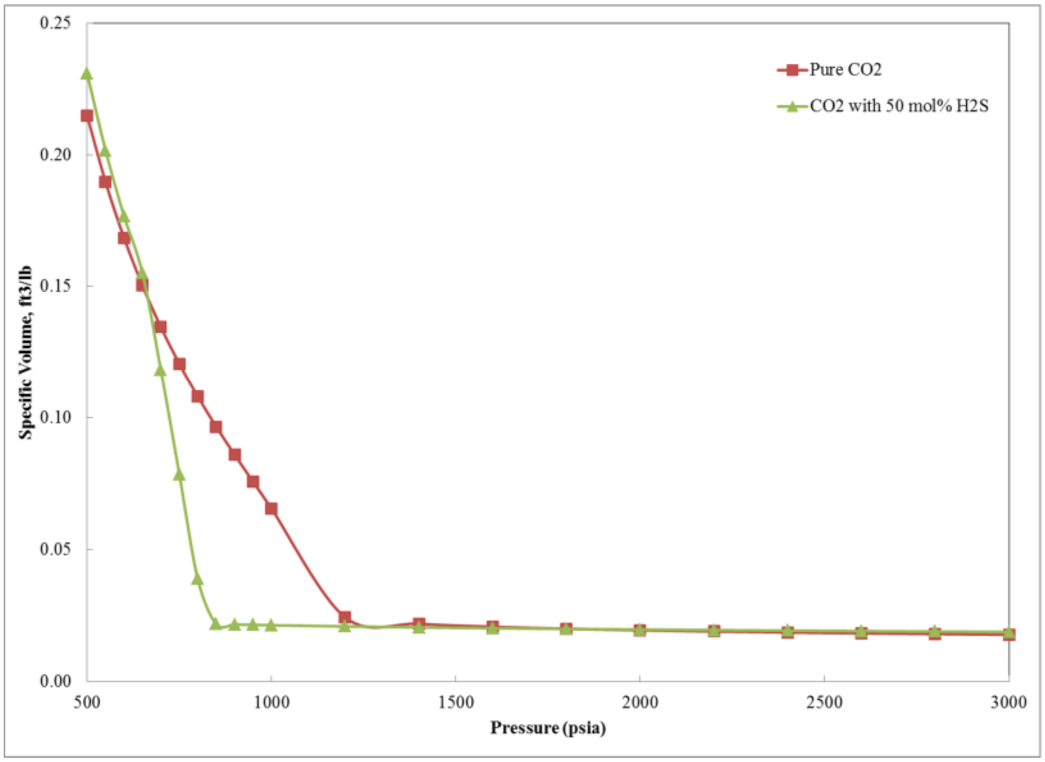

Figure 3. Specific Volume of Pure CO_2 vs. CO_2 with 50 % H_2S (molar) at 90 °F.

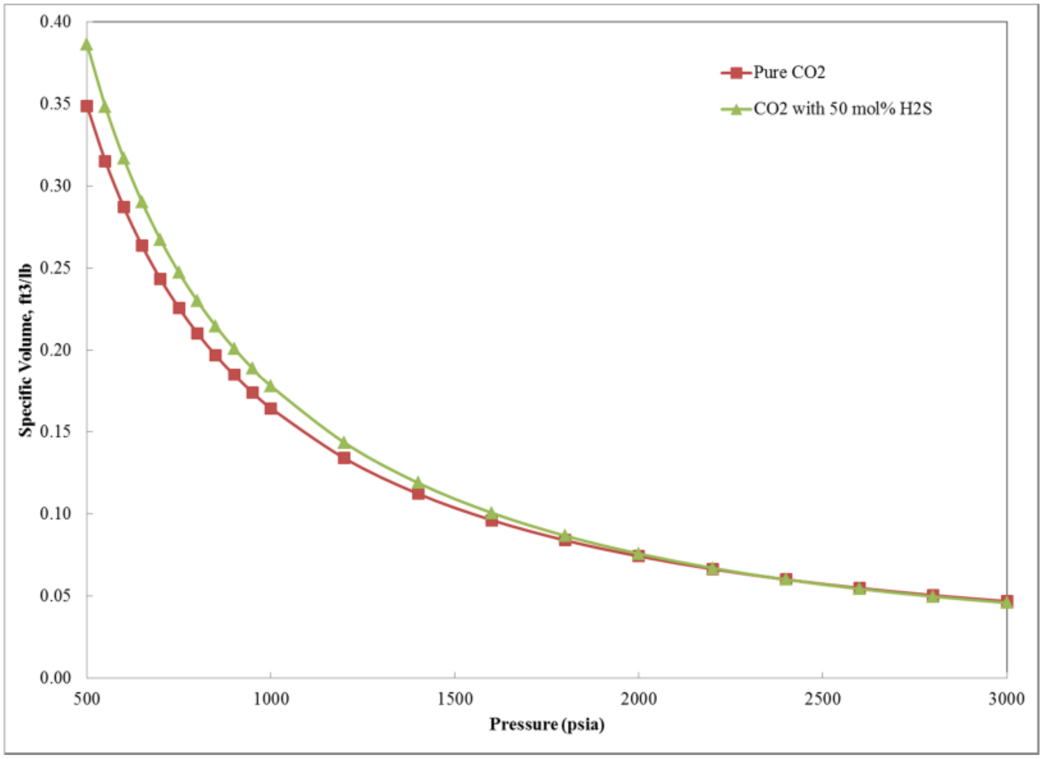

Figure 4. Specific Volume of Pure CO_2 vs. CO_2 with 50% H_2S (molar) at 300°F.

Given the differing physical properties at some conditions, a different conclusion may be drawn regarding sizing and selection of the valve if high H_2S content is expected. Table 6 shows the sizing results for the Example 1 scenario (200 MMSCFD with relief at 1,841 psia and 191 °F) for a pure CO_2 stream versus a high H_2S content stream. In this case, the high H_2S relieving fluid is a two-phase mixture with a vapor fraction greater than 0.5 so a K_d value of 0.85 was used in the sizing calculation.

Table 6. Sizing Results Using the Mass Flux Method with Pure CO_2 and CO_2 with 50% H_2S Streams – Example 1.

	Pure CO_2 Stream	CO_2 with 50 mol. % H_2S Stream	Percent Difference
Area Required (in.^{2})	4.61	4.52	-2.0%

In this comparison, there is a small difference between the calculated required areas for the two fluids and the presence of H_2S does not affect the ultimate selected orifice size (API "P"). This is not the case, however, in the Example 2 scenario (200 MMSCFD with relief at 1,599 psia and 110 °F). Table 7 shows the same comparison for the Example 2. In this case, the high H_2S relieving fluid is a saturated liquid so a K_d value of 0.62 was used in the sizing calculation.

Table 7. Sizing Results Using the Mass Flux Method with Pure CO_2 and CO_2 with 50% H_2S Streams – Example 2.

	Pure CO_2 Stream	CO_2 with 50 mol. % H_2S Stream	Percent Difference
Area Required (in.^{2})	4.63	3.59	29.1%

In this comparison, the required relief area for the stream with H_2S is significantly lower. If H_2S content is correctly accounted for, an API "M" orifice size is required, compared to the larger API "P" orifice required for a pure CO_2 stream.

Relief Gas Disposal Systems for Acid Gas Systems

Relief gas disposal systems for acid gas service may also require special consideration that is not necessary for more typical natural gas treatment facilities. CO_2 rich fluids expanding across a relief device into a low pressure system will experience significant cooling due to the Joule-Thomson effect and can form large quantities of solid CO_2 which should be avoided if practical to do so. There are two easy ways to avoid or minimize the formation of solid particles in the relief header system that are not always practical, but may be possible in a number of different situations. The first is to locate relief devices in the process where the relieving fluid will be at relatively high temperatures as it is relieved. A good example of this application would be on the discharge of positive displacement compressors where the relieving case is typically blocked discharge. In this situation, the relief device should be placed upstream of the gas cooler to minimize or eliminate the formation of solid CO_2 as the gas expands across the relief valve.

The second way to avoid solid formation of CO_2 in the relief gas disposal system is to route the relief devices that will form solid CO_2 when relieving directly to the atmosphere. This may not be an option when handling highly toxic (containing H_2S) or flammable fluids; however there are a number of cases where a pure or nearly pure CO_2 stream can be routed to the atmosphere directly. In these cases a short vent pipe that directs flow a safe distance away from operators and equipment is sufficient and can be designed to maximize the velocity of the fluid as it relieves to the atmosphere. It is important that the vent pipe be structurally sound and properly supported to withstand the thrust forces that will be generated when the relief valve opens.

When fluids must be treated by flaring, scrubbing, or some other process prior to discharge to the atmosphere, it is necessary to route the fluid into a relief disposal system whose design is dictated in part by API-521, *Pressure-relieving and Depressuring Systems*. It is not unusual to find relief systems that do not follow one or more of the guidelines presented in API-521, and in the case where CO_2 rich acid gas is forming solid particles as it relieves, following the standard becomes more important. The following items should be considered when designing a relief gas disposal system for acid gases.

- Materials of Construction – As the acid gas relieves across the relief valve, temperatures well below the minimum operating temperature of carbon steel may occur and necessitate that the acid gas relief system be constructed, at least in part, by a material like stainless steel. Compatibility of the material with the vented streams should also be considered; the presence of water in the acid gases or in the vent header may also lead to a need for stainless steel construction of the acid gas relief system.

- Piping Elevations – No pocketing of piping should be allowed and the relief device should be located at a maximum elevation relative to the relief header. Discharge piping should slope continuously from the relief device to the vent header and the vent header should slope continuously to the knockout drum.
- High System Velocities – High velocities in the acid gas relief disposal system can help prevent the accumulation of solids in the piping by entraining solids in the gas stream and preventing them from accumulating on piping walls. Allowed velocities in a relief disposal system can vary from company to company, but a typical range might be 0.5 - 0.7 Mach in the vent header.
- Pipe Fittings – Pipe fittings such as elbows should be minimized in the relief disposal piping to minimize areas where solids could build up and create an obstruction. No internals should be allowed in flare or vent knockout drums and no silencers or flame arresters should be permitted in the flow path to atmosphere.
- Segregated Headers – Segregating the acid gas relief header system should be considered, in particular the high pressure acid gas relief header system should be considered for segregation from the other relief header systems in the facility. There are practical process reasons and potentially economic reasons for isolating these headers from one another including:
    - The potential to form hydrates or other compounds if the low temperatures expected in the high pressure acid gas relief header mix with other relieving streams, which could inhibit the functionality of other relief systems.
    - Segregation may allow other relief headers to be constructed out of less costly materials, e.g. carbon steel rather than stainless steel.
    - The high pressure acid gas relief header will likely be smaller in diameter than the other relief headers in the facility. Consider the relief case in Example 1 where the relieving pressure is 1,841 psia, which is 110% of the set pressure 1,660 psig. Assuming a bellows-style relief valve is installed in this example, the allowed backpressure on the valve could conservatively be set at 488 psi (30% of the set pressure) which allows for a large amount of pressure drop between the outlet of the relief valve and the vent tip. This in turn allows the vent header piping to be smaller in diameter which minimizes the cost of the system, maximizes the system velocity, etc.

Strategies for Minimizing Relief Devices in Acid Gas Systems

Maintaining a relief device can be costly with regularly scheduled inspections and testing of the relief device as part of the required practice for a facility, particularly if it operates under the Process Safety Management (OSHA 1910.119) standard. Ongoing maintenance costs can be a significant economic driver to minimize the number of relief devices installed, as well as engineering costs during design, overall costs for larger disposal system piping and equipment, and the additional costs of the relief devices themselves.

An increasing amount of the CO_2 acid gas produced in the natural gas treatment industry and other industries is being used in Enhanced Oil Recovery (EOR) techniques, where CO_2 is compressed and pumped to high pressures and then injected into mature oil fields in order to produce more oil. The EOR CO_2 is usually transported by pipeline from the anthropogenic CO_2 source to the oil field. Economically transporting CO_2 by pipeline requires that the pipelines operate at high pressure; usually well above the critical pressure of 1,071.6 psia to take advantage of the high density of CO_2 at higher pressures. H_2S and CO_2 acid gases are also compressed and disposed of in underground formations via injection wells at acid gas disposal and other facilities and injection pressures at these facilities can also easily exceed 1,500 psig. In all of these scenarios, appropriately sized relief valves will be required.

The costs associated with designing, building, and maintaining a relief system in an acid gas application can be even greater than in a typical facility, particularly when the system is operating at high pressures. One major concern with high pressure acid gas systems is trapping dense phase fluid between two closed block valves or at other locations in a system such as in between the downstream side of a check valve and a block valve. The dense phase fluid is sensitive to ambient temperature changes and heat transfer from the surroundings and can easily overpressure piping components when blocked in and heated even a few degrees. The pressure of a constant volume of CO_2 as a function of temperature is shown in Figure 5.

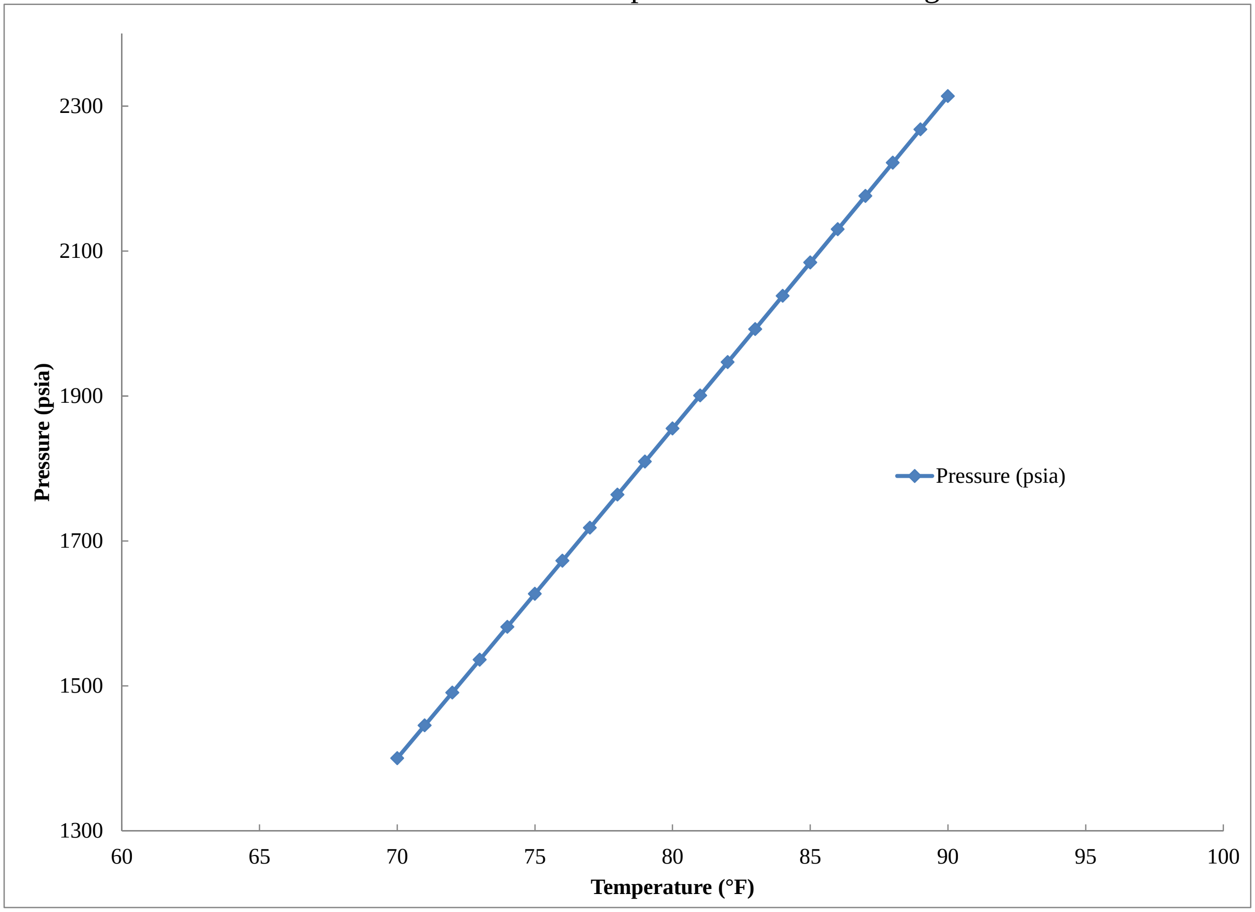

Figure 5. Pressure of CO_2 at a Constant Volume as a Function of Temperature.

The large pressure increase that can be caused by heating trapped CO_2 necessitates that the design of the system consider how to mitigate the potential for failure of piping and other components due to blocked in CO_2 heated by the surroundings. A common solution is to install thermal relief valves in between block valves and other places in the system where the fluid could otherwise be trapped, but this can be costly - particularly in cases where atmospheric venting is not permitted. There are several options to consider for mitigating the hazards in this scenario other than installing thermal relief valves:

1. Use the minimum number of block valves in the system that are absolutely required to safely operate and maintain the equipment. This will minimize the opportunities to trap the dense phase fluid between two block valves.
2. Develop and maintain an administrative controls policy that allows block valves that could otherwise lead to trapping of fluids to be locked in the open position.
3. If tight shutoff of the valve is not required, a small hole can be drilled in the valve that allows communication with downstream or upstream piping.

It is also important to be aware of the design of pumping and compression equipment in the acid gas handling system so that the downstream piping and vessels can be designed with sufficiently high design pressures. Once in the dense fluid state, it is common to use multistage centrifugal pumps that pump the dense phase fluid up to injection or pipeline delivery pressures instead of using gas compressors. The ideal solution to minimize the number of relief devices downstream of these pumps is to design the piping system such that the pumps are not physically capable of over-pressuring the downstream piping. This does not eliminate the need for thermal relief valves, however. The maximum discharge pressure for a centrifugal pump should be determined by the pump's maximum head curve at the maximum expected normal operating suction pressure. As an example, if the pump normally operated at a 1,300 psig suction pressure but the upstream system was vented when the pressure reached 1,450 psig, the 1,450 psig suction pressure may be used for determining the maximum discharge pressure. If the pump is capable of producing 1,000 psi of head then the discharge piping should be rated above 2,450 psig to avoid installing large relief devices. During this analysis, it is also important to consider the maximum temperature the piping will encounter downstream of the pump(s) as the pressure rating for piping decreases with increasing temperature.

A final strategy to consider in lieu of installing relief devices is the installation of a High Integrity Pressure Protection System (HIPPS). The HIPPS is a safety-rated control system that is allowed to take the place of a relief device to protect equipment. Figure 6 shows a very basic HIPPS set up that could be used to protect a downstream vessel from high inlet pressure. In the example shown in Figure 6 both valves upstream of the vessel will close if two of the three pressure transmitters indicate that the pressure in the vessel is reaching an unsafe level.

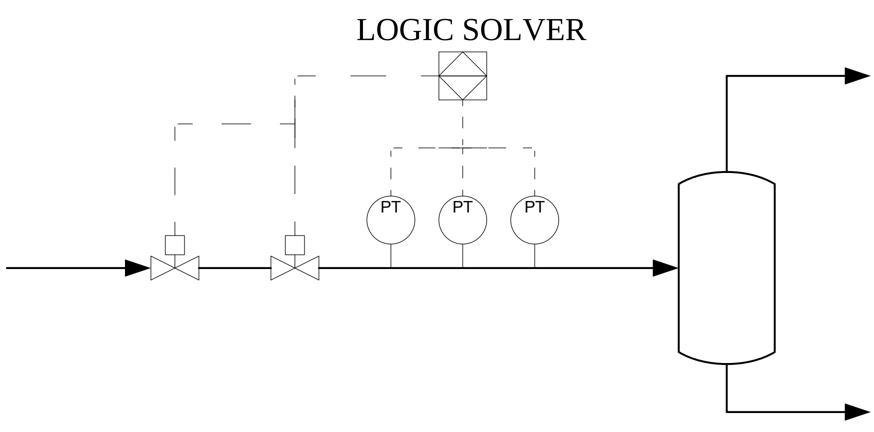

Figure 6. Simple HIPPS for Overpressure Protection.

The HIPPS has a safety instrumented level requirement of 3, which calls for redundant input and output devices, regularly scheduled testing intervals of instrumentation and valves, and the installation of a certified fault tolerant logic solver as the overall control system. The system typically uses multiple input signals to trigger redundant output devices to avoid over-pressuring downstream equipment. The HIPPS does not keep the downstream system from potentially requiring a fire case relief valve and may introduce a scenario where dense fluid can be trapped between block valves. These systems can be costly to install and maintain and may only be feasible where high flow rate relief requirements make relief devices impractical or where existing relief disposal systems are not adequate to relieve a new gas source.

Conclusions

There is a wide range of temperature and pressure conditions in acid gas systems where the ideal method for sizing relief valves is inappropriate and the more rigorous mass flux method should be utilized to size the relief valve. In these situations the physical properties of the fluid from the relieving pressure down to the system backpressure need to be known with a high degree of accuracy. Process simulation tools can be used for estimation of the physical properties but results should be checked against known data sources to be sure that the information is accurate. The designer is also cautioned to use a value for the discharge coefficient K_d that is appropriate for the fluid state and the valve.

Acid gas disposal and pipeline transportation systems can operate at very high pressures to facilitate injection and to make transport of the acid gas more economical. At pressures above the critical point the acid gas will have the ability to overpressure piping components if trapped between two block valves if the acid gas is subjected to any heating from the surroundings. The number of relief devices in an acid gas system can be minimized by proper design early in the project and by developing robust administrative policies that prohibit trapping dense phase fluid between two block valves. Furthermore, piping downstream of rotating equipment like multistage centrifugal pumps should be designed such that the pump cannot overpressure the discharge piping based on the maximum suction pressure at which the pump would continue to operate and the maximum head that can be produced by the pump.

When relieving acid gases into a vent or flare header it is necessary to consider the materials of construction of the vent header. The high pressure drop and resulting Joule-Thomson cooling that the acid gas will undergo when relieving from high pressure may require that the vent piping be constructed out of material other than carbon steel. The potential to form solids, either from the acid gas stream itself or from other species present in the vent header, might require that the acid gas vent header be isolated from other relief headers in the plant, be designed with a direct routing that minimizes pipe fittings, and operate at a high velocity during relief events.